IMPROVING THE 10" HEAD ALLIANCE COUPLER AND KNUCKLE

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SUMMARY

The 10" head Alliance coupler has seen extensive use in various regions of the world since its inception a hundred years ago. The increasing demands of heavy haul trains has facilitated the need for improvements to this design and by examining failed in service coupler and knuckles key locations of failure were identified. Through a combination of physical measurements and 3D laser scanning an initial 3D CAD model was created of the standard Alliance coupler and knuckle. Non-linear finite element static strength analyses and strain life fatigue analyses were performed on these models with results compared to failures in service. Physical static tension tests were used to validate these FEA results.

An improved coupler and knuckle were designed addressing known causes of failures. The RIS Alliance coupler had an increase in strength, a reduction in localized yielding under typical in service loads and an increase in fatigue life in known failure areas. Improvements to the patent pending RIS HD knuckle included an increase in strength of approximately 20% and an increase in fatigue life by approximately 55%.

Thus the improved *Rail Industry Supplies* Alliance coupler and Heavy Duty knuckle offer significant improvements to fatigue life and strength while maintaining interchange ability with existing Alliance coupler sub parts.

INTRODUCTION

While heavy haul operators with axle loads greater than 35 tonne typically use F type couplers, some heavy haul operators prefer to use the shorter Alliance 10 inch head coupler resulting in shorter train lengths. This allows the continued use of existing infrastructure such as short crossing lengths and unloading facilities. Additionally, as the Alliance coupler is the preferred coupler for intermodal trains in Australia and elsewhere in the world, operators running both intermodal and heavy haul fleets have the benefit of reduced inventory lines when only using one coupler type.

As the in-train forces that are experienced by heavy haul trains exceeds that of their intermodal and general counterparts, it is desirable that the strength of both the coupler and corresponding knuckle is increased for heavy haul use. Further it is noted that some heavy haul trains in Australia have traction force capabilities of > 2.0MN, and that in-train forces may exceed 3MN resulting in operational failure of knuckles designed to the AAR standard of 2.9MN.[1]

To optimize the service life of the knuckle, the knuckle should be designed as close to 70% of the strength of the coupler body as possible ensuring it is still the weakest link in the "draw gear chain". By maximising its fatigue life and ultimate strength, this increases the probability that the knuckle is condemned due to wear rather than failure, thus resulting in the maximum service life permissible for a given coupler strength. Consequently it is important that any gains made with the knuckle strength are likewise achieved with the coupler.

While many design changes were possible which could result in an increased coupler and knuckle strength, it was deemed paramount that any changes made allowed the improved knuckle to be fitted retrospectively to standard 10" head Alliance couplers and to function interchangeably. It was also deemed paramount that standard knuckles could still be used with the improved coupler.

NOTATION

AAR	Association of American Railroads
ASF	American Steel Foundries
CAD	Computer Aided Design
FEA	Finite Element Analysis
HD	Heavy Duty
MCB	Master Car Builders Association
MPI	Magnetic Particle Inspection
RIS	Rail Industry Supplies
TTCI	Transportation Technology Center Inc.

A BRIEF KNUCKLE COUPLER HISTORY

In 1873 Eli H. Janney patented a semi-automatic railway coupler which was the first commercially successful version of the Knuckle Coupler. In 1875 there were more than 900 car coupler patents and by 1900 approximately 8,000 coupler patents had been issued.[2]

To combat the growing number of coupler designs, in 1911 the MCB (the forerunner to the AAR) requested that the coupler manufacturers work with the MCB to develop a new coupler whose parts would be interchangeable regardless of their manufacturer. This resulted in the development of the Type D coupler which was adopted in 1916 as the standard coupler for use in the USA.[3]

By 1930 the Type D coupler was improved further resulting in the Type E coupler, but interchange ability of parts between Type D and E couplers was not maintained. This Type E coupler is still the standard coupler in use in the USA today. In 1954, AAR also designated the Type F Interlocking Coupler as an alternative standard coupler to the Type E. The Type F coupler is commonly used in heavy haul applications.

STANDARD ALLIANCE COUPLER

Originally produced in Alliance, Ohio, from which it derives its name, the standard Alliance coupler was developed concurrently to the Type D coupler by ASF. It was designed to be a lower weight and used a 10" head length which was shorter than the 12" head length of their Type D counterpart.

Subsequently, when the Type D was selected by the MCB as the standard coupler for the United States Interchange Network, the Alliance coupler was marketed by the Amsted Corporation, the parent company of ASF, as the "Standard Coupler for the World". This resulted in the licensing of the design to different manufacturers in various countries. As such, Alliance couplers have been sold in South America, Australasia and Africa with the first production of the design in Australia occurring as early as 1926.[4]

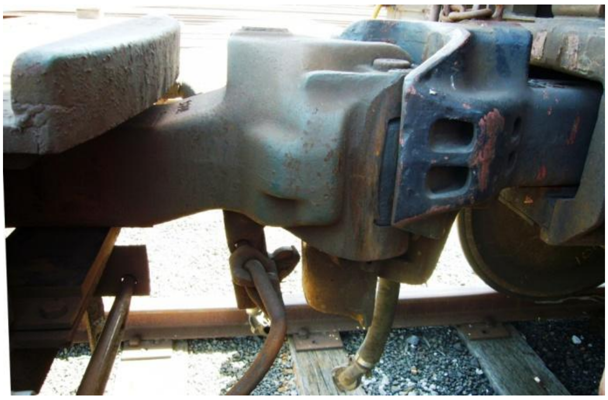

Figure 1 : Upset & Straight Alliance Couplers

While the Alliance coupler is not governed by the AAR[5], national regulatory authorities in the various countries where the coupler is used may require AAR design requirements to be met. For example, in Australia AS 7524.2[6] dictates that coupler bodies and knuckles should meet the permanent set and ultimate strength requirements prescribed in AAR Specification M-211[7]. These requirements are seen in Table 1.

	Permanent Set Test		Minimum Ultimate Load (kN)
	Load (kN)	Maximum Set (mm)	
Knuckle	1,780	.76	2,890
Coupler Body	3,110	.76	4,000

Table 1 : AAR Coupler Strength Requirements

KNOWN FAILURE AREAS IN SERVICE

Over the last 100 years since its initial design, the Alliance coupler has undergone evolutionary improvements including the improvement of material properties from AAR M-201[8] Grade B to Grade E steel. However, the increased demands of today's heavy haul applications has resulted in common failure areas. From field examinations of failed Alliance couplers and knuckles, a number of primary failure locations were identified.

1. Standard Alliance Coupler

Coupler failures were typically found in the following locations:

1. Bottom pulling lug including hole in floor;
2. Excessive wear and deformation of coupler pin supports;
3. Cracking between lower scallop of coupler throat opening and guard arm;
4. Longitudinal upper web / tie bar behind push face;
5. Cracking through internal parting line of coupler head where locking block is fitted;

Figure 2 : Hole in Bottom Pulling Lug Floor

Figure 3 : Deformation of Coupler Pin Support

Figure 4 : Cracking between Throat and Guard

Figure 5 : Cracking through Longitudinal Web

2. Standard Alliance Knuckle

Field examinations of failed Alliance knuckles, revealed two primary failure locations:

1. Neck region of the knuckle, which is the thin region between the pulling lugs and the knuckle shoulders. An example of failure in this region is seen in Figure 6.
2. Knuckle Pin Hole. An example of failure in this region is seen in Figure 7.

Similar locations of failure have also been found to exist in standard E type knuckles.[9]

Figure 6 : Knuckle Failure through Neck

Figure 7 : Knuckle Failure through Pin Hole

3. Knuckle Magnetic Particle Inspection

Additionally, MPI was conducted on Alliance knuckles from three different manufacturers that had been used on a heavy haul train of 9,000 ton. Of the knuckles tested that exhibited fatigue cracking, irrespective of

manufacturer, the primary location for cracking occurred through the neck region. Fatigue cracking in this region can be seen in Figure 8 and is a known failure area. Metallographic examination revealed that fatigue cracking was often associated with weld repairs or casting defects in this region.

Figure 8 : MPI Showing Fatigue Cracks

STRESS ANALYSIS USING FEA

Initial 3D CAD models were created of an existing Alliance coupler and knuckle currently used in Australia. This was achieved through a combination of physical measurements and 3D laser scanning. The models were then meshed, restraints and loading conditions were applied and material properties were defined. Non-linear static strength FEAs were then undertaken using the NASTRAN solver to identify areas of high stress, possible causes of failure and to ensure the AAR M-211 strength requirements were met.

1. Coupler Static Strength FEA

The coupler body was restrained in accordance with AAR M-211 with the pulling lugs subjected to the following loading conditions to determine the:

- Permanent Set resulting from a load of 3,110kN. Results shown in Table 2.
- Stresses from a load of 2,000kN. Results in Figure 9 and Figure 10.

	Permanent Set (mm) @ 3,110kN Load
Lower Pulling Lug	2.3
Upper Pulling Lug	1.9
Lower Pin Support	0.8
Upper Pin Support	0.8
Guard Arm	0.2

Table 2 : STD Coupler Static Strength Results

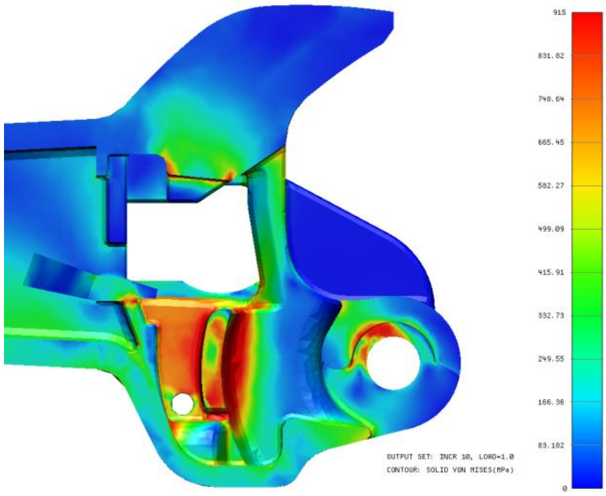

Figure 9 : Static Strength FEA at 2,000kN Load - Standard Alliance Coupler Lower Half

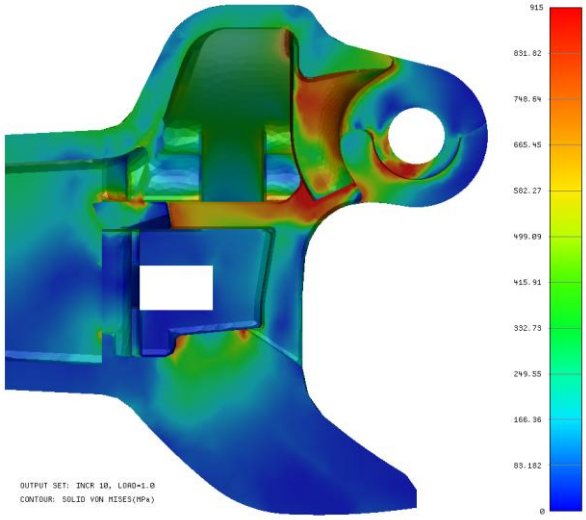

Figure 10 : Static Strength FEA at 2,000kN Load - Standard Alliance Coupler Upper Half

From the examination of real world failures and the results of FEA, the majority of the failure modes identified can be directly attributed to the load path through the coupler when under draft. The draft load is predominantly transferred by the upper and lower coupler pulling lugs. When a draft load is applied, the load path for the upper half of the coupler head is predominantly through the central longitudinal rib, also known as a tie bar member, shown in Figure 5. Consequently, this web, a known failure location, experiences high tensile stresses which are transferred to the coupler shank. Likewise, for the lower half of the coupler head, the load path occurs directly behind the bottom pulling lug through the pulling lug floor to the coupler shank. This bottom pulling lug region is also a significant location of coupler failure.

Thus both the primary upper and lower load paths converge at a horizontal internal parting line region at the rear of the coupler head

where there is a significant disjoint in geometry. This lends rise to another location of failure, resulting in cracking through the internal parting line of the coupler head where the locking block is fitted.

Further, in draft both upper and lower coupler / knuckle pin supports, in addition to the locking block, act as reaction faces to resist the rotation of the knuckle within the coupler head when in the locked position. These pin supports also partially transfer the draft load. These pin supports are subjected to high loads resulting in excessive wear and plastic deformation as can be seen in the FEA results and couplers in service. While wear is expected to normally occur at these pin supports and at the pulling lugs, it is desirable to reduce the amount of yielding as it can result in a redistribution of reaction forces in the coupler / knuckle resulting in forces in regions that differ significantly from design.

2. Knuckle Static Strength FEA

The knuckle / knuckle pulling contact face was subjected to the following longitudinal loading conditions to determine the:

- Stresses from a draft load of 2,000kN. Results can be seen in Figure 11.
- Permanent Set resulting from a draft load of 1,780kN. Results in Table 3.

To resist the force applied, the knuckle pulling lugs and part of the pin supports were restrained in the longitudinal direction, the locking block contact face and part of the pin supports were restrained in the lateral direction and the base of the knuckle at the pin opening was restrained in the vertical plane.

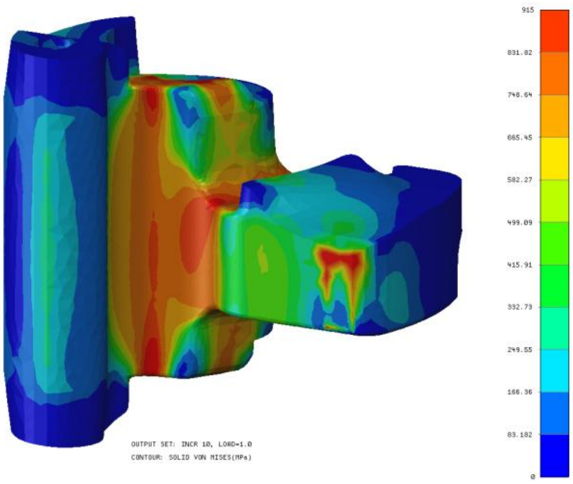

Figure 11 : Standard Knuckle Static Strength FEA at 2,000kN Load

From field examinations of failed knuckles, two primary failure locations were identified. These were through the knuckle neck and through the knuckle pin hole. Examination of the failure faces indicated that both brittle failure and fatigue failure modes were present highlighting the need to improve both the ultimate strength and fatigue strength of the knuckle. Further, MPI demonstrated the initiation of fatigue cracking specifically through the knuckle neck.

Both the static FEA and fatigue strength FEA also indicated that the two locations of failure would occur through the knuckle neck and the knuckle pin hole. As such, the FEA findings agreed with the real world failure modes witnessed.

3. Physical Static Strength Testing of Knuckle

To ensure the validity of the FEA results, physical static strength tests were performed as per AAR M-211. The Alliance knuckle and coupler were connected to the test rig with a dummy knuckle fixture used to load the coupler assembly as shown in Figure 12. A comparison between the FEA and physical test results can be seen in Table 3.

Figure 12 : Physical Static Testing

	Permanent Set (mm) @ 1,780kN Load
AAR Requirement	0.76 (max)
Knuckle FEA Result	0.35
Knuckle Physical Result	0.3

Table 3 : STD Knuckle Static Strength Results

As can be seen in Table 3, the static strength FEA and physical test results were very close in values, with only an approximate 15% variance. This slight difference in values was most likely to be accounted for by a variation in material properties between the minimum AAR Grade E yield and tensile strength values used in the FEA and the slightly higher material strength values that occur in actual production. Thus the results of physical testing only further validated the FEA stress analysis and confirmed that the restraints and loading conditions used were appropriate.

FATIGUE ANALYSIS USING FEA

While a static strength FEA is useful in identifying areas of high stress in static loading, such loading conditions do not typically cause failure unless manufacturing defects are present resulting in brittle failure.[10] Rather, the majority of coupler failures are fatigue failures caused by fluctuating loads.[11] Although the Alliance coupler is not governed by AAR requirements, and local standards may not require fatigue testing, best practice would dictate that the fatigue requirements of AAR Specification M-216[12] are used as a benchmark.

Fatigue failure can be divided into two basic groups, high cycle fatigue where the magnitude of the stress is low and where deformation is predominantly elastic, and low cycle fatigue where the magnitude of the stress is higher and plastic deformation occurs. As the dynamic loads experienced by the coupler typically exceed the yield point of AAR Grade E steel, a strain life fatigue analysis approach was deemed more suitable than a stress life approach.

The total strain life is mathematically defined by the Manson–Coffin–Basquin relationship:

$$\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'}{E}\left(2N_f\right)^b + \varepsilon_f'\left(2N_f\right)^c \qquad (1)$$

Where:

$\frac{\Delta\varepsilon}{2}$ = total strain amplitude

σ_f' = fatigue strength coefficient

b = fatigue strength exponent

ε_f' = fatigue ductility coefficient

c = fatigue ductility exponent

E = modulus of elasticity

$2N_f$ = number of cycles to failure

From testing performed by the TTCI[13], the following strain life curves were established as an estimate for couplers/knuckles produced from AAR Grade E steel. The two curves reflect the range of quality of test specimens due to differences in fatigue properties of the cast material or the surface finish of the part in locations of high stress.

$$\frac{1126}{E}\left(2N_f\right)^{-0.264} + 0.61\left(2N_f\right)^{-0.57} \qquad (2)$$

$$\frac{1126}{E}\left(2N_f\right)^{-0.164} + 0.61\left(2N_f\right)^{-0.58} \qquad (3)$$

Using the 3D CAD model developed of an existing Alliance coupler and knuckle, a NASTRAN based strain life fatigue analysis was subsequently performed with the loading conditions specified in AAR Specification M-216[14] applied. To provide a minimum and maximum fatigue life estimate of the coupler and knuckle, the strain life curves defined by equations (2) and (3) respectively were used. These curves represent fatigue data of mean minus one standard deviation, and thus reflect a survival rate of about 68% of the population.

1. Coupler Fatigue FEA

The fatigue analysis results of the standard Alliance coupler are recorded in Table 4. The maximum estimated life for the known critical areas are shown which represent a 68% survival rate until crack initiation. While the areas identified via FEA as likely regions of fatigue cracking agree with in-service failures, caution should be taken when comparing the relative severity of these areas. For example, these results indicate that the region around the upper pulling lug and longitudinal upper web is the area most prone to fatigue cracking. While in some instances this has proven to be true, examination of in-service failures reveals that this is not always the case. This difference may be due to variations in the clearance between the coupler and knuckle pulling lugs as a result of casting tolerances.

Location on Coupler	Number of M-216 Cycles
Lower Pulling Lug	1.0e+6
Upper Pulling Lug	0.4e+6
Upper Pin Support	0.8e+6
Lower Pin Support	0.8e+6
Longitudinal Upper Web	0.2e+6

Table 4 : Standard Coupler Fatigue Results

2. Knuckle Fatigue FEA

The fatigue analysis results of the standard Alliance knuckle are recorded in Table 5. As can be seen, the maximum estimated life representing a 68% survival was 480,000 cycles based on life until crack initiation. This crack initiation occurred in the upper region of the neck.

In comparison, the AAR requirement of an average of 600,000 cycles defines failure as the occurrence of separation of any segment of the knuckle from the parent structure. It should also be noted that the fatigue requirements of AAR M-216 are intended for Type E and F knuckles which are noticeably thicker than the Alliance, and thus they could be expected to exhibit a greater fatigue life.

	Number of M-216 Cycles
AAR Min. Requirement	400,000
AAR Average Requirement	600,000
Standard Alliance Knuckle: Minimum Life Estimate	120,000
Standard Alliance Knuckle: Maximum Life Estimate	480,000

Table 5 : Standard Knuckle Fatigue Results

HEAVY DUTY COUPLER

From the examination of real world failures and the results of FEA, it was clear the locations where the coupler should be improved. However, due to the internal geometry of the coupler head, there were limitations as to where the geometry of the coupler could be altered while maintaining functionality with the standard Alliance knuckle. One such region that was significantly restricted was the coupler / knuckle pin supports where only minor improvements were able to be implemented.

In contrast, special attention was focused on the lower pulling lug region where the pulling lug was able to be blended more gradually into the floor region, and the floor thickness increased. Additionally, the need for a hole in the lower pulling lug floor was removed which eliminated this crack initiation site. Similarly, there was a special focus on reducing the stresses in the upper pulling lug and the upper longitudinal rib (tie bar member). This was achieved by reducing the overhang of the pulling lug, increasing the width of the longitudinal rib and blending it more gradually between the front buff face and the rear of the coupler head.

To minimise the likelihood of cracking through the internal parting line at the rear of the coupler head, a single internal core was used for the coupler head. This single core eliminated the parting line and allowed for a more blended shape between the upper longitudinal rib and the lower push face. Consequently, the upper and lower load paths in draft were able to be transferred to the coupler shank without the previous disjoint in geometry causing a stress raiser. Lastly, to mitigate against cracking between the scallop of the coupler throat opening and the guard arm join, the size of the scallop was reduced while the fillet behind it increased. Both ends of this crack region were blended to minimise crack initiation.

1. Static Strength FEA

A new 3D CAD model was created of the improved RIS Alliance coupler. The RIS coupler was subjected to the same loading conditions as the standard Alliance coupler and a non-linear static strength FEA was performed. The FEA result of the analysis from a typical in-service load of 2,000 kN can be seen in Figure 13 and Figure 14. Further investigation of this result revealed that peak stresses were reduced significantly in the upper and lower pulling lug region and the longitudinal web.

A comparison between the permanent set for a standard and RIS Alliance coupler can be seen in Figure 15. Due to the reduction in localised yielding in known failure areas and increased stiffness of the RIS coupler head, the guard arm of the RIS coupler is seen to exhibit a marginally higher permanent set.

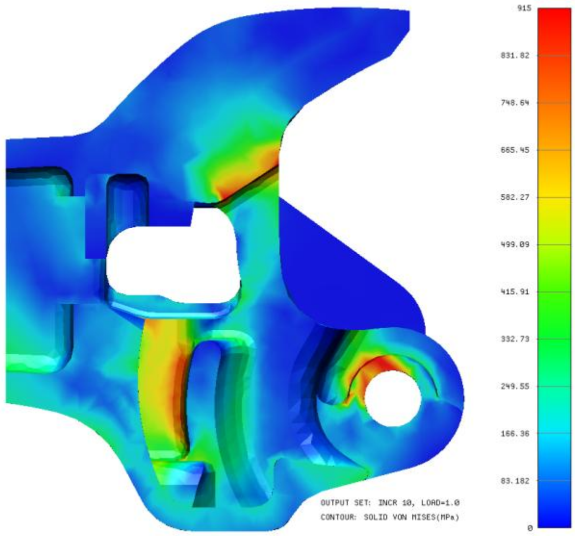

Figure 13 : Static Strength FEA at 2,000kN Load - RIS HD Alliance Coupler Lower Half

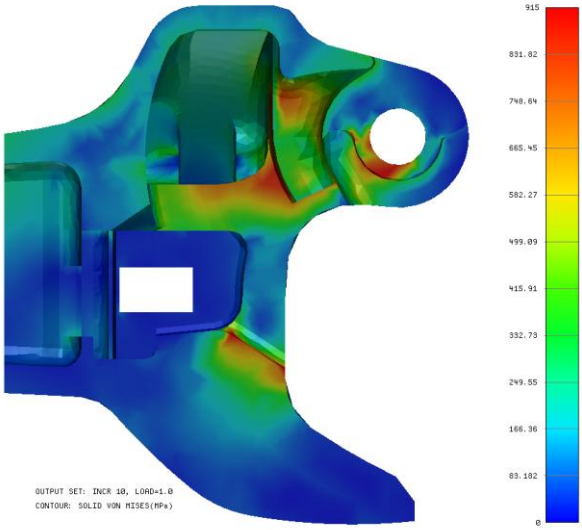

Figure 14 : Static Strength FEA at 2,000kN Load - RIS HD Alliance Coupler Upper Half

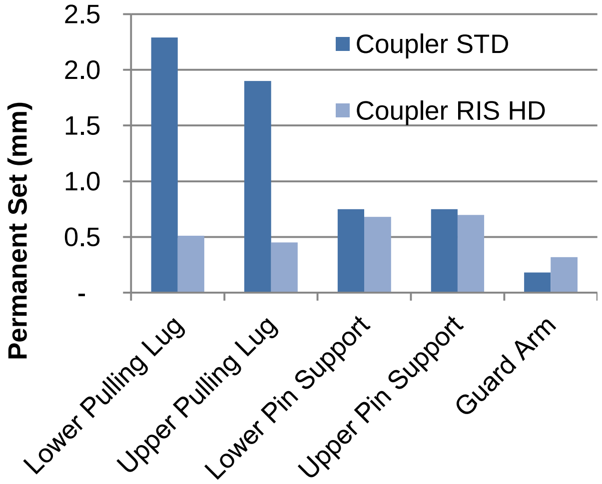

Figure 15 : Coupler Permanent Set Comparison

2. Fatigue Strength FEA

A NASTRAN based strain life fatigue analysis was run on the RIS coupler. Figure 16 compares the maximum estimated life results of known failure areas with the results from a standard Alliance coupler.

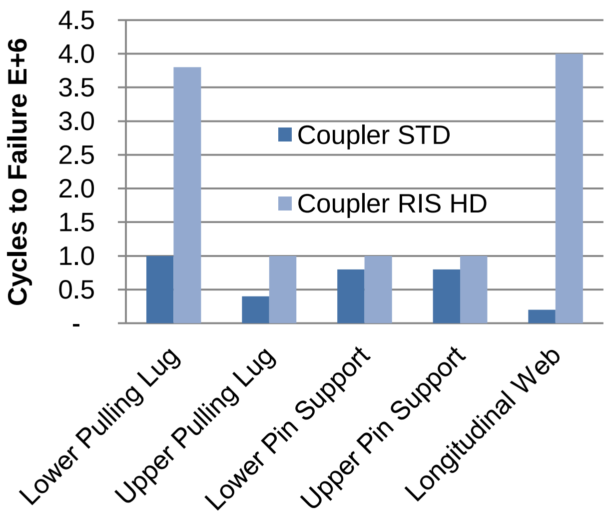

Figure 16 : Comparison of Coupler Fatigue

HEAVY DUTY KNUCKLE

From the examination of real world failures and the results of FEA, it was clear that the knuckle needed to be primarily improved through the neck region and through the knuckle pin hole as a secondary measure. Due to the internal geometry of the coupler head, there were limited areas where the geometry of the knuckle could be altered while maintaining functionality with the standard Alliance coupler head. One area that was able to be modified was the upper half of the neck region. Subsequently, various geometric arrangements were modelled and FEA tests were performed to determine whether improvements could be made in this region. After testing many different configurations, a patent pending design was established which included a gusset from the upper shoulder to the valley floor of the top pulling lug. This patent pending design reduced peak stresses in the neck region leading to improved fatigue properties while still being able to fit within the standard Alliance coupler head.

1. Static Strength FEA

A new 3D CAD model was created of the improved RIS HD Alliance knuckle which included the addition of the gusset amongst other improvements. As a means of comparison with the standard Alliance knuckle, the HD knuckle was subjected to the same loading conditions and a non-linear static strength FEA was performed. The result of the analysis from a typical in-service load of 2,000kN can be seen in Figure 17. Peak stresses in the neck region were decreased by approximately 20%.

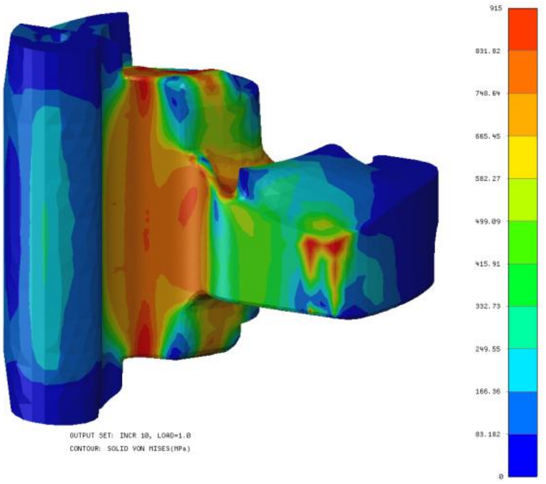

Figure 17 : RIS HD Alliance Knuckle Static Strength FEA at 2,000 kN Load

A comparison between the permanent set for a standard Alliance knuckle and the RIS HD knuckle can be seen in Figure 18. Similarly, an approximate 20% reduction can be seen for the permanent set resulting from a load of 1,780 kN. This delay in yielding in the neck region leads to a significant increase in fatigue strength due to the low cycle / high load nature of the fatigue loading spectrum.

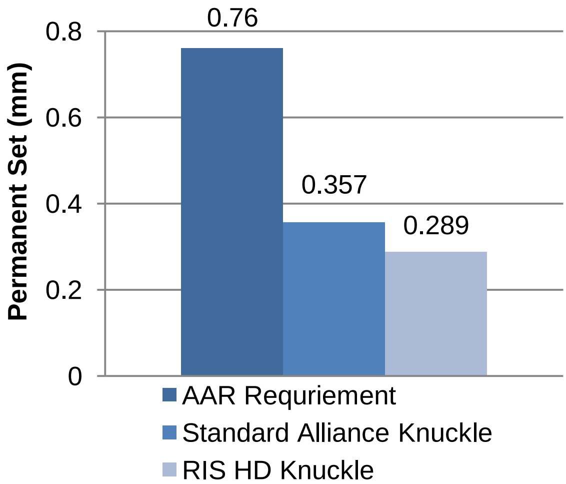

Figure 18: Knuckle Permanent Set Comparison

2. Fatigue Strength FEA

A NASTRAN based strain life fatigue analysis was run on the RIS HD knuckle. Results of this analysis can be seen in Figure 19, and compares these results with the results from a standard Alliance knuckle. It is seen that 68% of knuckles are expected to exceed a minimum and maximum fatigue life of 180,000 and 770,000 cycles respectively. Subsequently, an average 55% improvement

can be seen in the knuckle fatigue life through the neck region which compares favourably to the fatigue requirements of AAR M-216.

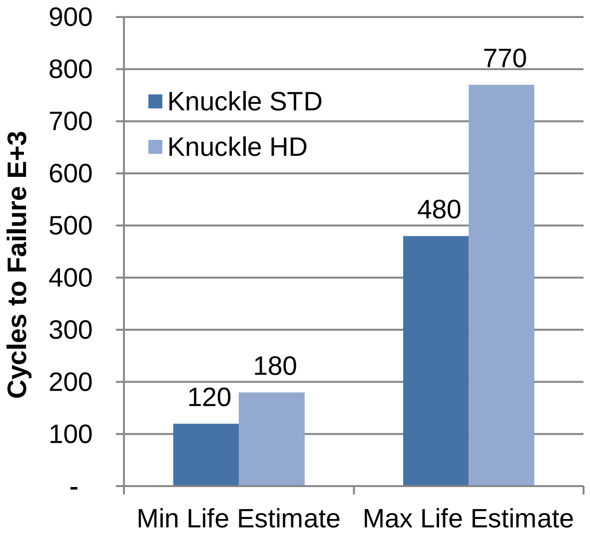

Figure 19 : Comparison of Knuckle Fatigue

Due to geometric restrictions to enable interchange ability, no significant improvement was achieved through the knuckle pin region either in static or fatigue loading.

ALLIANCE COUPLER / KNUCKLE SYSTEM

1. Life of Coupler Bottom Pulling Lug

Fatigue analysis performed by the TTCI on Type E couplers indicates that the lower coupler pulling lug has a relatively short life until crack initiation, even if no surface defects are present.[15] Examination of a Type E knuckle reveals that the upper and lower pulling lugs are eccentric about the coupler mid plane. The offset from the mid plane to the upper pulling lug is about 25% greater than to the lower pulling lug. Consequently, the lower half of the knuckle has a higher stiffness than the upper half resulting in the lower coupler pulling lug being loaded disproportionately.

This disproportionate loading is even more pronounced in Alliance couplers where the difference in offset between upper and lower lugs is in the order of 40%. This lower pulling lug bias may be partly responsible for fatigue failure around the lower coupler pulling lug as seen in service. While attempts have been made to minimise fatigue failures at the lower coupler pulling lug, many attempts forego interchange ability with existing coupler designs.[16]

However, due to the increased neck width of the RIS HD knuckle, the difference in offset between upper and lower pulling lugs is almost negligible while still maintaining interchange ability with existing Alliance couplers. Thus a near symmetric loading of the coupler should occur potentially leading to increased life of the lower coupler pulling lug.

2. Bushed End vs F End Shank

In addition to improvements to the coupler head, the function of the coupler in the overall draw gear system was examined. A first principles and FE analysis of the standard Alliance bushed coupler / yoke / pin interface was undertaken and compared with a standard AAR F End. The additional degree of freedom of the F End, namely pitch, resulted in lower induced yoke stresses leading to an increased service life of the corresponding yoke fitted with an F end coupler. Subsequently, it is recommended that new Alliance couplers utilise a F End replacing the typical cylindrical bushed end of the Alliance coupler.

3. Coupler / Knuckle Strength Ratio

As discussed at the start of this paper, to ensure the knuckle remains as the weakest link in the draw gear, the knuckle strength should be designed as close to 70% of the strength of the coupler body as possible.

Using non-linear FEA, the standard Alliance knuckle and RIS HD knuckle were able to be compared with confidence. As has been discussed, the RIS HD knuckle exhibited an approximate increase in strength of 20%. Physical testing and FEA indicated that this significant increase in knuckle strength resulted in a knuckle approaching 70% the strength of the RIS coupler body.

4. Rapid Prototyping and Functional Fitment

To ensure existing coupler sub-parts, such as the knuckle and locking block, fitted the improved coupler and knuckle design, existing coupler sub-parts were 3D laser scanned and virtually fitted within the 3D CAD model. To further confirm correct fitment of sub-parts and the correct functionality of the coupler, a rapid prototype of the improved coupler and knuckle were created using ABS plastic. Thus feedback on design functionality was able to be obtained promptly and without associated tooling costs.

5. Manufacturing Defects, Surface Finish and Material Fatigue Life Properties

As mentioned, two different strain life curves were used to estimate the fatigue life of the coupler and knuckle. These two curves reflected the range of quality of test specimens due to differences in fatigue properties of the cast material, and the surface finish of the part in locations of high stress. As can be seen by the estimated minimum and maximum fatigue lives of the knuckle in Figure 19, the manufacturing quality of the product has a significant effect on its overall fatigue life.

Additionally, research has highlighted the need for adequate corrosion protection in critical areas to reduce corrosion and associated fatigue crack initiation.[17]

CONCLUSION

A hundred years ago, the growing number of coupler designs led the MCB to develop a new coupler whose parts would be interchangeable regardless of their manufacturer. While ultimately the Alliance coupler was not the selected option, it has still seen use worldwide including in some heavy haul applications. The increasing demands of heavy haul trains has facilitated the need for improvements to this design. These improvements were made ensuring that the issues of interchange ability experienced a hundred years ago were not encountered again.

Improvements to the RIS Alliance coupler included:

- Peak stresses in known failure regions were decreased
- A decrease in localized yielding from typical in-service loads
- Fatigue life of known failure areas was increased

Improvements to the patent pending RIS HD knuckle included:

- Peak stresses in the neck region were decreased by approximately 20%
- Measured overall permanent set of the knuckle decreased by approximately 20%
- Fatigue life increased by approximately 55%

Thus the RIS Alliance coupler and HD knuckle offer significant improvements to fatigue life and strength.

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